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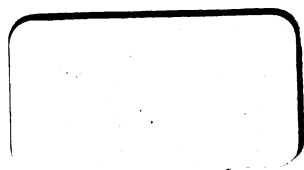
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PAPERS

ON

WATER SUPPLY.

BY

PROFESSOR WILLIAM RIPLEY NICHOLS,

OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

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1880.

THE POLLUTION OF STREAMS.

①

THE WESTFIELD AND MERRIMAC RIVERS.

By THE SECRETARY. *Charles Folger Folson.*

POLLUTION OF A BROOK BY SULPHURIC ACID.

By PROFESSOR NICHOLS.

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1880. Aug. 13,
Gifford
The Author.

THE WESTFIELD RIVER.

IN continuation of the investigations begun by Mr. J. P. Kirkwood, C. E., under the direction of the Board, in 1875, the Westfield River basin, lying partly in Franklin, Berkshire, Hampshire, and Hampden Counties, has been examined during the year. The survey was made by Mr. E. R. Hamilton, C. E., the more important localities having been afterwards visited by the secretary of the Board. The chemical examinations were made at the laboratory of the Massachusetts Institute of Technology, by Professor W. Ripley Nichols.

GENERAL DESCRIPTION OF THE WESTFIELD RIVER BASIN.

The Westfield River rises in the town of Savoy, in the north-eastern part of Berkshire County: its general direction is southerly and easterly. Savoy is a farming town, as are the neighboring towns of Windsor and Plainfield, which are drained by the Westfield River next below Savoy. About three miles south-east of Windsor is the village of West Cummington, at which place there is a paper-mill that gives employment to forty hands. There are also a wood-working shop, and a very small paper-mill which employs but three men, a mile and a half below. These are the only manufactures in Cummington, except saw-mills. The next towns drained by the Westfield River are Worthington and Chesterfield, both of which are very thinly-settled farming communities.

Twenty miles south of the village of Cummington, at the village of Huntington, and a little above it, the main river is joined by the West and Middle Branches.

The Middle Branch rises in the eastern part of the township of Peru, and flows in a southerly and easterly direction to its junction with the main river; it drains the easterly

parts of Peru and Middlefield, all of the town of Worthington, and the eastern part of the town of Chester. The entire section of country drained by the Middle Branch is a thinly-settled agricultural district, and has no manufactures.

The West Branch rises in Washington, and runs in a south-easterly direction to its junction with the main river at Huntington. It drains the eastern part of Washington and Becket, the southern part of Middlefield, all of Chester but the northern part, and the northern part of the town of Blandford. At North Becket there is a tannery and currying shop, employing thirty hands, and turning out three hundred hides per week. It is stated that the tannery is about closing up, and that the business is to be transferred to New York State, where bark can be bought cheaper. At Middlefield Station, on the Boston and Albany Railroad, three miles below Becket Station, there is a paper-mill employing seventeen hands, where they turn out about two tons of manilla paper per day. Another mill, not yet completed, about half a mile farther down the river, will be of nearly the same size as the last-named, and will manufacture wall-paper. This building is to replace one which was destroyed by fire July, 1879. North of Middlefield Station, two and a half miles up Factory Brook, there are two broadcloth-mills, which together employ seventy-five hands, and produce about five hundred yards of cloth per day. At Chester Village, a few rods up Walker Brook, four miles below Middlefield Station, there is a tannery which employs eleven hands, and turns out thirty hides per day. About a quarter of a mile above this tannery, on the same brook, there is an emery-mill. Between Chester and Huntington villages, on the north bank of the river, there are two emery-mills; but the only refuse from such works is stone and iron dust.

At Huntington, eight miles below Chester, there is a woollen-dress-goods mill, employing one hundred and twenty hands, running sixteen hundred and twenty spindles and seventy looms. The water below the mill is at times much discolored by the dye-stuffs, and in hot, dry weather gives off an unpleasant odor, but is not sufficiently offensive to cause general complaint. On the main river, half a mile above its junction with the West Branch, is a paper-mill

employing seventy hands. These are the only manufactures at Huntington.

Blandford, which lies south of Huntington and Chester, is a thinly-settled farming town; as is Montgomery, which lies just below Huntington on the north bank of the river.

A mile and a half below Huntington, in Russell, on the south bank of the river, is a paper-mill employing one hundred hands, manufacturing fine writing-paper. About five miles below this mill, on the same side of the river, and in the same town, is another paper-mill of the same capacity, and making the same kind of paper.

Five miles farther down the river is Westfield, which is the largest town in the Westfield basin, and the only one that has a full public supply of water. In West Springfield there is a partial supply. In all the other towns the inhabitants are supplied with spring-water from the neighboring hills and by wells. The source of supply for Westfield is among the hills in Montgomery, and is very pure spring water. There are plans for a system of sewers for Westfield, but no definite action has been taken towards building them as yet. At present the largest part of the direct drainage of the town is into Town Brook, which is a rapid stream running through the middle of the town, and emptying into the Westfield River about a mile below. Westfield lies on a plain, surrounded by high hills; but the soil is sandy, and easily absorbs all surface water. The principal business of the place is the manufacturing of whips and cigars, there being thirty whip-manufactories and about forty cigar-manufactories. The whip-factories are run by steam-power, and neither they nor the cigar-factories have any offensive refuse. Besides the whip and cigar factories, there are two machine-shops and a church-organ factory, also two paper-mills on the Little Westfield River.

Directly south of Westfield, lies the town of Southwick, the greater part of which is in the Westfield River basin. It is a thinly-settled farming community, and contains no manufactories. Below Westfield, the river drains the westerly part of the township of Holyoke, the westerly and extreme southerly part of the town of West Springfield, and the northern part of the town of Agawam, and finally empties into the Connecticut River opposite the city of Spring-

field. The portion of Holyoke that drains into the Westfield River is a quite hilly and very thinly-settled region, and contains no manufactories. The portion of West Springfield drained by the Westfield River contains two paper-mills and one cotton-mill. The land rises well up above the river, and is naturally well drained; the soil is sandy. It is not a thickly-settled community. The same is true of the land on the south side of the river, in the town of Agawam.

The whole country lying within the limits of the Westfield River basin is a thinly-settled, hilly region, abundantly supplied with the purest water, and naturally well drained. The soil is mostly of a sandy nature. The river and most of its branches have a steep fall along their entire length; and, the current being in consequence very swift, the small amount of impurities which are let into the river from the few and widely separated manufactories are very soon rendered imperceptible to sight, taste, or smell. The water throughout the country is apparently very pure. The whole region within the basin is very free from any nuisances caused by town-sewage or manufacturing-refuse, the only exceptions being in the discharge of spent tan-bark in North Becket from a tannery, and the refuse from the woollen-mills in Middlefield and Huntington, from both of which there is some complaint of occasional nuisance.

AREA AND POPULATION.

The Westfield basin has an area of 529.58 square miles, calculating the line of the water-sheds as nearly as can be done by means of the maps now in existence, and without making a special survey for that purpose.

The population of the towns lying in considerable part within the basin was 26,501 in 1855, 26,416 in 1865, and 30,006 in 1875. Small portions of the population of Savoy, Windsor, Peru, Goshen, Washington, and Granville, — from one-eighth to one-fourth, — and not far from three-fourths of the population of Ashfield, Agawam, and West Springfield, lie outside of the drainage area of the Westfield River. The population within its water-shed has been estimated at 22,141 in 1865, and 24,365 in 1875, an increase of ten per cent in ten years, and being at the rate of 46 to the square mile.

Westfield is the only town having over 1,500 inhabitants

within the Westfield River basin, except possibly Chester, in which the new industry opened in the emery-mills has probably caused a moderate increase in the population since the last census; the greater parts of Agawam and West Springfield drain into the Connecticut River.

The twenty-two towns showed a slight decrease in their number of inhabitants between the censuses of 1855 and 1865. In the next ten years, there was an increase of fourteen per cent. During the twenty years, Chester increased eleven per cent, Westfield eighty-four per cent; the two towns draining chiefly into the Connecticut River, Agawam and West Springfield, increased respectively forty-six per cent and seventy-eight per cent. The remaining eighteen towns had smaller populations in 1875 than in 1855. The increase of population within the drainage area of the Westfield River and its tributaries between 1865 and 1875 was due to the prosperity of four towns overbalancing the emigration from the other eighteen.

The following table shows the distribution and movement of the population in the last twenty years :—

TABLE I. — *Population of Towns in Westfield Basin.*

TOWNS.	Population, 1855.	Population, 1865.	Population, 1875.
Savoy	919	866	730
Windsor	905	753	624
Plainfield	652	579	481
Ashfield	1,342	1,221	1,190
Peru	487	494	443
Cummingtōn	1,004	980	916
Gosben	471	411	349
Worthington	1,112	925	818
Washington	1,068	859	603
Middlefield	677	727	603
Chesterfield	950	801	746
Becket	1,472	1,393	1,329
Chester	1,255	1,266	1,396
Huntington	1,172	1,163	1,095
Blandford	1,271	1,087	964
Russell	677	618	643
Montgomery	413	353	304
Granville	1,316	1,367	1,240
Southwick	1,130	1,155	1,114
Westfield	4,575	5,634	8,431
Agawam	1,543	1,664	2,248
West Springfield	2,090	2,100	3,739
Total	26,501	26,416	30,006

From the statistics above, it does not seem likely that any of the rural hill-towns will ever increase much more in population. Chester and Huntington have several manufactories and mills, but they are not likely to become large towns; Westfield is well situated for growth; while West Springfield and Agawam, lying directly opposite the flourishing city of Springfield, may reach considerable importance in size and prosperity.

WATER-SUPPLY AND SEWERAGE.

Pure water has been introduced in West Springfield and Westfield from storage-basins built by damming pure streams,—in the case of Westfield, from a mountain-brook in Montgomery. The supply is abundant, and free from danger of pollution. The other towns depend chiefly upon wells,—springs being occasionally used by individuals, and commonly with them lead-pipe.

There have been for several years propositions to introduce sewerage in Westfield; and with its abundant water-supply that may now be considered the chief sanitary need of the town. In the portion of West Springfield draining into the Connecticut River, about a square mile of territory has been protected by dikes from overflow of the rivers, and that part has been provided with sewers. The remaining towns depend chiefly upon vaults and cesspools.

The mills, as a rule, discharge all their refuse directly into the streams, including the contents of the water-closets, &c. This pollution of the water is seriously complained of, so far as could be learned, only at the paper-mill in Middlefield, where the spent tan from the tannery in Becket is sometimes a source of inconvenience. It can hardly be said that the excrement of a thousand operatives, and the refuse from mills so few in number, so small, and so widely separated, would affect the condition of the river differently, whether discharged directly into it or through town sewers.

POLLUTION OF THE RIVER.

At the present time, there is no noticeable pollution of the streams in the Westfield basin except from the tannery in Becket and from the mills in which scouring or dyeing is done; and, as a rule, even this is to be observed only for a

few hundred yards — or in some cases as many rods — while the vats are discharging. The spent dye-liquors, in Middlefield, are said to sometimes discolor the stream for a couple of miles, as is also the bark from the tannery in Becket. Commonly, nothing would be seen to markedly contaminate the river. The direct drainage of towns into it is inconsiderable. The towns, for the most part, have the neat appearance characteristic of New-England villages, their chief danger with regard to the subject of drainage being the pollution of wells by privies, &c. The river is rapid, and its volume is so great that no legislation is likely to be needed to preserve its purity, even if the sewers so much needed in Westfield should discharge directly into the stream. Indeed, twenty-five thousand people could be provided for without rendering the river offensive, and probably without injuring its water for use at the mills below, in West Springfield; even in the driest seasons, the least flow of the river recorded having been 35,547,431 gallons in twenty-four hours.

As suggested in previous reports of the State Board of Health, it is desirable to restrict the mills somewhat in their wholesale discharge of all sorts of refuse into the nearest river, especially when that can be done without any serious detriment to their interests.

DESCRIPTION AND LOCATION OF THE MILLS.

In the mills for the finer kinds of paper, the rags are first thoroughly dusted by beating, the dust being carried off by means of a fan. The rags are then cut into small pieces about an inch or two square, sorted according to their quality, and then dusted again. They are then put into a rotary boiler, with one barrel of lime to two tons of rags, and boiled for twelve hours. The rags are then washed twelve hours in running water, ground more or less fine according to the length of fibre desired, put through the beaters and beaten until the pulp is of the requisite fineness, then run through the rollers which make it into sheets, and finally run through the sizing. Different quantities of alkali and different kinds are used in different places, according to the stock used and the amount of cleansing needed by it. In the manilla-paper mills, the process is essentially the same; coarser stock is used, however, and the pulp is not ground so fine nor bleached so white.

The process in tanneries is to soak the hides, and then scrape off the "fleshings," to drench them in lime to remove the hair, and then put them in a strong mixture of hen-manure and water, soaking them finally in the bark-liquor. The refuse consists of animal matter in suspension, hen-manure, lime, and ground tan-bark.

In the woollen-mills, the worst refuse comes from washing the wool with soap and alkalies. Some of the coarser coloring matters discolor the streams very much just after the emptying of the vats; but the tendency is more and more, each year, to use the more expensive and concentrated dyes, from which the waste is very small.

In the only cotton-mill in the basin, there is no bleaching or dyeing, and excrement from the closets is the chief refuse.

At the Crescent Paper Mills in Russell, the excrement is kept out of the stream and used as a fertilizer, as is the case also with the refuse from the paper-mill of Messrs. Crane Brothers in Westfield.

In the next table, are given the manufactures in the Westfield basin, exclusive of grist-mills, emery-mills, saw-mills, cigar-shops, whip-manufactories, and any others that do not pollute the streams. The amount of stock, &c., used is given as stated by the superintendents of the various mills.

TABLE II. — *Polluting Factories in the Westfield River Basin.*

NAME OF RIVER OR STREAM.	Description of Mill.	Location.	Head, and Fall in Feet.	No. of Hands employed.	Quantity of Materials used per Day.
Westfield River . . .	Paper . . .	W. Cummington . .	28	40	1,500 lbs. rags; 1 bbl. lime; 50 lbs. chloride of lime; 50 lbs. soda-ash; 100 lbs. animal sizing.
Westfield River . . .	Paper . . .	W. Cummington . .	20	3	600 lbs. sacking; $\frac{1}{2}$ bbl. lime; 200 lbs. chloride of lime.
West Branch . . .	Tannery . . .	North Becket . . .	-	30	$\frac{1}{2}$ bbl. lime; $\frac{1}{2}$ bush. manure; $8\frac{1}{4}$ tons bark.
Factory Brook . . .	Broadcloth . . .	Middlefield . . .	15	30	800 lbs. wool and shoddy; logwood, chrome, red tartar, vitriol, sumach, coppers, and blue vitriol.
Factory Brook . . .	Broadcloth . . .	Middlefield . . .	-	45	
West Branch . . .	Paper . . .	Middlefield . . .	27	17	3,000 lbs. stock; 80 lbs. chloride of lime; 1 bbl. lime; 20 lbs. soda-ash.
Walker Brook . . .	Wall Paper . . .	Middlefield . . .	18	17	Nearly the same as the above.
Walker Brook . . .	Tannery . . .	Chester . . .	17	11	2 tons bark; $\frac{1}{2}$ bush. hen-manure.
West Branch . . .	Dress Goods . . .	Huntington . . .	10.5	120	400 lbs. wool; 80 lbs. silk; 170 lbs. cotton.
West Branch . . .	Paper . . .	Huntington . . .	15	70	3,200 lbs. rags; 450 lbs. animal sizing; $1\frac{1}{2}$ bbl. lime; 200 lbs. chloride of lime; 80 lbs. alum.
Westfield River . . .	Paper . . .	Russell . . .	22	100	3 tons rags; 320 lbs. lime; 33 lbs. chloride of lime; 80 lbs. soda-ash; 600 lbs. animal sizing; 100 lbs. alum.
Westfield River . . .	Paper . . .	Russell . . .	22	100	Same as previous mill.
Little Westfield River . . .	Paper . . .	Westfield . . .	20	75	2 tons rags; $\frac{1}{2}$ cask chloride of lime; $\frac{1}{2}$ bbl. lime; $1\frac{1}{2}$ bbl. soda-ash.
Little Westfield River . . .	Paper . . .	Westfield . . .	12	17	2 tons rope and sacking; 75 lbs. chloride of lime; $\frac{1}{2}$ bbl. lime.
Westfield River . . .	Paper . . .	West Springfield . .	27	70	3,000 lbs. rags; 150 lbs. lime; 25 lbs. chloride of lime; 25 lbs. alkalies; 500 lbs. animal sizing; a little rosin sizing.
Westfield River . . .	Cotton . . .	West Springfield . .	32 } 255	255	4,500 lbs. cotton.
Westfield River . . .	Paper . . .	West Springfield . .		90	3,500 lbs. stock; 300 lbs. chloride of lime; 140 lbs. lime; 140 lbs. animal sizing.
Westfield River . . .	Paper . . .	Agawam . . .	8	40	$1\frac{1}{2}$ tons rags; 270 lbs. lime; 140 lbs. chloride of lime; 200 lbs. animal sizing.

The summary of these statistics appears in the following table.

TABLE III. — *Summary of Manufactures.*

	Number.	Operatives employed.
Paper-mills	12	639
Tanneries	2	41
Cloth-mills	2	75
Dress-goods.	1	120
Cotton-mill	1	255
Total	18	1,180

The amount of water at the various points¹ was measured and calculated approximately by Mr. Hamilton, as shown in the following table, after a heavy rain. If only one-fourth of these quantities represents the dry-weather flow, there will still be much more than enough in the river-bed at all times to dispose of all the sewage that is likely to be discharged into it for at least very many years, if not for all time.

TABLE IV. — *Flow of Water at Various Points in the Westfield Basin in Twenty-four Hours.*

	A.	B.	C.	D.	E.
Cubic feet .	45,969,120	30,240,000	8,640,000	13,824,000	8,208,000
Gallons. .	343,872,921	226,210,925	64,631,693	103,410,708	61,400,108

The quite dry-weather flow at the point A is stated to be 84,919,581 gallons² in twenty-four hours; the least recorded is 35,547,431 gallons.

TABLE V. — *Summary of Statistics.*

Drainage-area in square miles	529.58
River-flow (dry weather) in 24 hours, cubic feet at A	11,352,096
River-flow (dry weather) in 24 hours, U. S. gallons	84,919,581
Number of factories	18
Number of factories per square mile	0.034
Number of operatives in the factories	1,180
Population in 1865	22,141
Population in 1875	24,365
Population per square mile	46

¹ See the map.² W. Chapman, chairman of selectmen.

Considering the great volume of the river, and its rapid flow, and also the small amount of impurity discharged into it from towns and mills, one is prepared to find very little evidence of contamination, as is shown in the following table, where the numbers 5 to 1 refer to points on the map. The water is very soft.

TABLE VI. — *Examination of Water from Westfield Basin.*

[Results expressed in parts in 100,000.]

DATE OF ANALYSIS.	Locality on the Map.	UNFILTERED WATER.		SOLID RESIDUE.		Total at 212° F.	Chlorine.
		Ammonia.	"Albuminoid Ammonia."	Inorganic.	"Organic and Volatile."		
Nov. 15	5	0.004	0.015	1.64	2.44	4.08	0.10
Oct. 30	4	0.001	0.011	2.76	2.16	4.92	0.12
Oct. 30	4	0.002	0.009	3.04	1.74	4.78	0.16
Oct. 30	3	0.001	0.007	2.88	0.92	3.80	0.12
Oct. 30	3	0.001	0.005	2.53	1.47	4.00	0.11
Oct. 30	2	0.003	0.009	3.32	1.16	4.48	0.18
Oct. 30	2	0.003	0.008	3.34	1.46	4.80	0.19
Oct. 30	1	0.003	0.009	4.02	1.12	5.14	0.20
Oct. 30	1	0.004	0.011	3.90	1.22	5.12	0.17

The waters were quite clear, and not very much colored; the first five in order were rather more colored than the remaining four. No one of them gave any re-action for nitrates in the unconcentrated water by the ferrous sulphate test.

THE MERRIMAC RIVER.

A PRELIMINARY examination of the Merrimac River was made Sept. 25, 1879, the results of which it seems desirable to give this year, although it was not possible to carry the inquiry so far as it was the original intention to do, leaving fuller investigations for a subsequent report.

The water was taken for analysis at Lowell by the secretary, and in Lawrence by Mr. J. C. Hoadley, of the Board, when the river was somewhat fuller than in the ordinary dry-weather flow. The first two specimens were taken in Lowell, above Pawtucket Dam, and from the northerly and southerly sides respectively of the river, about one hundred feet from the banks, opposite the service-pipe for the direct supply of the city. No. 3 was from the Merrimac River, below all the sewers and outlets for the refuse of the mills, and just opposite its junction with the Concord River, from which No. 4 was taken. The reservoir (5) was supplied at that time from the filter-gallery (6), which is really a large, deep well near the bank of the river. No. 7 was taken seventy feet from the north shore, over the end of the direct supply-pipe. No. 8 a little higher up, two hundred feet from the shore. No. 9 was from the vicinity of the "snag,"—a pile anchored with a heavy stone in the channel, and from the surface where the river is thirty feet deep. The last (No. 10) was from the main channel, one hundred and fifty feet from the shore of the island. The last four were collected in the late afternoon, ten hours after the first four, as that time represents about the interval between a certain body of water's leaving Lowell, and reaching Lawrence.

The quantity of water flowing in the Merrimac River at Lawrence, on the date of the examination, was, for the twelve hours from 6.30 A.M. to 6.30 P.M., nearly 4,600 cubic feet

per second; in the succeeding twelve hours, nearly 1,100 cubic feet; or at the average rate per second for the twenty-four hours of 2,850 cubic feet.¹

The results of chemical examinations made by Professor Edward S. Wood, M.D., at the laboratory of the Harvard Medical School, are as follows:—

TABLE VII. — *Results of Examination of Merrimac-River Waters.*

[Figures express parts per 100,000 of water.]

LOCATION.	Free Ammonia.	"Albuminoid" Ammonia.	Chlorine.	RESIDUE.			Hardness.
				Fixed.	Volatile.	Total.	
1. Lowell — above the city . . .	0.0040	0.0128	0.40	2.00	3.00	5.00	1°
2. Lowell — above the city . . .	0.0054	0.0136	0.40	2.00	2.00	4.00	1°
3. Lowell — below the city . . .	0.0021	0.0132	0.40	3.25	2.25	5.50	1°
4. Lowell — below the city . . .	0.0021	0.0128	0.30	2.75	2.50	5.25	1°
5. Lawrence — Reservoir . . .	0.0034	0.0164	0.40	5.60	8.70	9.30	1½°
6. Lawrence — Filter Gallery . . .	0.0013	0.0100	0.45	5.25	8.75	9.00	1-1½°
7. Lawrence — River, near N. shore . . .	0.0021	0.0140	0.40	5.50	3.00	8.50	1½°
8. Lawrence — River, opp. No. 5. . .	0.0021	0.0128	0.40	2.50	2.50	5.00	1-1½°
9. Lawrence — River, near "Snag" . . .	0.0021	0.0128	0.50	7.00	3.50	10.50	1½°
10. Lawrence — River Channel . . .	0.0008	0.0128	0.45	3.50	2.75	6.25	1°

If we compare No. 3, taken below all the sewers and mills of Lowell, with the average of 1 and 2, taken above the dam, we find a considerably less amount of ammonia, probably accounted for by the thorough aëration of the water in the fall over the dam; almost precisely the same amount of albuminoid ammonia; the same amount of chlorine; much more fixed residue (1.25), attributable² to street-washings, the immediate proximity of the mills, and surface-drainage generally; a little (0.25) less volatile residue; one part per hundred thousand more total residue, and the same hardness.

Averages from a considerable number of specimens would probably give somewhat different results from these just stated; but it is not likely that the present error is very great, and the samples were taken at 8.30 o'clock in the morning, when the discharge from the sewers was very considerable. A certain amount of oxidation might naturally take place while the water is passing over the high dam; but the sewer-outlets are below that point, so that there can be hardly any room at 3 for disappearance of the filth of the

¹ These measurements were kindly furnished by Mr. Hiram F. Mills, C. E.

² The samples were taken just after a moderate rain.

city by oxidation. A large part of the refuse from the mills might readily sink to the bed of the stream, being of greater weight than the water, taking with it some of the suspended organic matter; but the chief cause of the failure to clearly detect traces of a large city's refuse is in its enormous dilution, — the sewage of the city, twice as dilute as that of English cities, being mixed with six hundred times, or nearly a thousand times, its volume of water, in dry weather, according as the flow is calculated for twenty-four hours, or, as is more proper, for the twelve hours from 6.30 o'clock A.M. to 6.30 o'clock P.M.

In No. 4 is seen the influence of the admixture of the waters of the Concord River, into which is discharged a comparatively small portion of the Lowell filth, and which is less polluted in its general course before reaching the city, than the Merrimac River.

No. 5 is about the same as No. 6, as would naturally be the case, with an addition of a small amount of ammonia and albuminoid ammonia, due to its storage in a large open reservoir, exposed to the air, rain, and sun.

A couple of miles below Lowell, the water is considerably agitated by passing over Hunt's Falls, but, ten miles lower still, three out of four of the specimens (7-9) show the amount of ammonia unchanged: the albuminoid ammonia remains the same for the four; the chlorine is increased in only two; while the fixed residue, volatile residue, and total solids differ considerably, but perhaps no more than might be expected in a stream constantly receiving accessions to its volume from deep springs, &c., containing varying amounts of inorganic matter, which, not being thoroughly mixed with the general current, do not admit of accurate determination. At all events, it is found in practice that specimens of water, taken at the same time from adjoining places in a river, rarely agree entirely in their chemical constitution.

On all of the points which have just been stated, it is desirable to speak with a certain degree of reserve, until they can be confirmed by the examination of a large number of specimens. As they stand, so far as indicating sensible pollution of the river is concerned, they agree with the results published by the State Board of Health in their fifth report (p. 76), in a paper prepared by Professor William Ripley

Nichols, who made his chemical determinations from July, 1873, to January, 1874; those above Lawrence, however, having been made from the 9th to the 25th of September.

TABLE VIII. — *Results of Examination of Merrimac-River Water.*

[Results expressed in parts per 100,000.]

	Ammonia.	Albuminoid Ammonia.	Chlorine.	RESIDUE.		
				Fixed.	Volatile.	Total.
Mean of 11 examinations above Lowell, 1873 . .	0.0047	0.0114	0.14	2.37	1.73	4.10
Mean of 5 examinations above Lowell, September, 1873	0.0049	0.0124	0.13	1.76	1.88	3.64
Mean of 2 examinations above Lowell, September, 1879	0.0047	0.0131	0.40	2.00	2.50	4.50
Mean of 5 examinations below Lowell, July, 1873	0.0046	0.0098	0.16	3.39	1.52	4.91
1 examination below Lowell, September, 1879 . .	0.0021	0.0132	0.40	3.25	2.25	5.50
Mean of 12 examinations above Lawrence, September, 1873	0.0044	0.0110	0.20	2.41	1.69	4.10
Mean of 4 examinations above Lawrence, September, 1879	0.0018	0.0131	0.44	4.62	2.94	7.56

It may be seen that the amounts of ammonia and albuminoid ammonia, at the different places and times, did not vary enough to warrant any positive deductions as to impurities, except that, in 1879, the amount of free ammonia below the dam diminished to one-half the amount found above it, as was not the case in 1873. For this curious fact no explanation is at present offered; indeed, it may have been accidental.

The amount of chlorine found in all the places was, in 1879, from two to three times as great as in 1873, although in no case excessive; while the relations between the amounts found in the three points in the river were very nearly the same, both years. The Merrimac River rises in a large, navigable, fresh-water lake, and flows through a farming region, not highly cultivated, beside receiving the drainage of the manufacturing cities of Concord, Manchester, and Nashua, and of its tributary the Nashua River. Under these circumstances, it would be natural for the amount of chlorine to vary from time to time; and it may be that those limits would include the variations just shown between the results of examinations in 1873 and 1879, — a point to be decided by making a large number of determinations at different times.

So far as the residue is concerned, it may be readily seen from Table VII. how wide a range must probably be allowed for natural differences in the character of the water, irrespective of any pollution by cities and mills. The four specimens taken at Lawrence exhibit the character of the stream in this respect. The results, however, so far as they go, seem to show to a slight extent the influence of the refuse from the city sewers, and perhaps the mills also, on the river at Lowell. In 1873, the means of the various analyses appear to show that, in flowing from Lowell to Lawrence, the water regained about the same degree of purity which it had above Lowell; while in 1879 that inference would not be fully supported. A different deduction, however, might be made if the averages were from a greater number of specimens, extending over considerable periods of time. Between the points examined just below Lowell and those above Lawrence there is no city-drainage or pollution from mills.

POLLUTION BY SULPHURIC ACID.

THE following account by Professor Nichols, of the accidental discharge into a brook of sulphuric acid, is an interesting illustration of the fact already stated, that seemingly great amounts of contamination may be easily lost sight of in large volumes of water.

On the night of June 2, 1879, a fire occurred in a chemical works situated on a brook whose waters eventually find their way into Mystic Pond, from which a portion of the city of Boston, Mass., obtains its supply of water. As a result of the destruction by fire of the sulphuric-acid chambers, a considerable quantity of sulphuric acid, estimated at fifty tons of oil of vitriol, together with salt cake and other chemicals, was washed directly into the brook, or flowed upon the adjoining meadow-land, from which it would slowly find its way to the stream. Large numbers of fish driven before the acid water, or actually killed by it, passed into the mill-ponds below and through the wheels of the mills. Anxiety was felt lest the acid should reach Mystic Pond itself; and, five days after the fire, specimens of the water were brought to Professor Nichols of the Institute of Technology for analysis. As far as Mystic Pond itself was concerned, the fears proved groundless; but in the brook and in some of the upper ponds there was an abnormal amount of dissolved matter and especially of sulphates. The most interesting point, however, was with reference to the *acidity* of the water. As a rule, our surface waters in Massachusetts are naturally slightly alkaline, and, when the water is evaporated to dryness, the residue effervesces, at least slightly, when treated with acid.¹ It was found that even five days after the fire the water of the brook itself and of the nearest ponds was distinctly acid. The amount of acid was estimated by means of a dilute solution of baryta, using rosolic acid as an indicator.

The acidity was found to be as follows, the results being expressed by stating how many parts by weight of sulphuric acid (H_2SO_4), or its equivalent, were present in one hundred thousand parts by weight of the water; and also by stating, in round numbers, with how many parts of water, by weight, one part of sulphuric acid was diluted.

¹ Whether the alkalinity is to be regarded as due in part to the presence of alkaline carbonates, or as solely due to the presence of dissolved carbonate of calcium, is uncertain, as there are no analyses which are sufficiently particular to determine.

No.	DATE.	LOCALITY.	ACIDITY.	
			Parts of Acid in 100,000 of Water.	Parts of Wa- ter for one of Acid.
I.	1879. June 7, A.M.	From brook just below works	1.74	57,500
IV.	June 7, A.M.	Lower end of Richardson's Pond, about 1½ miles below works	0.74	135,000
V.	June 7, A.M.	Frye & Thompson's Pond, about 3 miles below works .	0.37	270,000
II.	June 7, P.M.	From brook midway between Chemical Works and Richardson's Pond, about ½ mile below works .	0.18	555,500
VI.	June 7, P.M.	From canal at Montvale, about 3½ miles below works .	0.37	270,000
III.	June 8, P.M.	Upper end of Richardson's Pond	0.15	666,600

The localities may be fixed by reference to a map on p. 394 of the second annual report of the State Board of Health. I is marked 2 on the map, and represents a point just below the chemical works in a brook about three feet wide and two feet or so deep. II is about one-half a mile below I on the brook. III is about one-half a mile below II, and at the entrance of Richardson's Pond, which is a half-mile long and about twenty rods wide. IV is at the lower end of Richardson's Pond. V is about three miles below the works, at Frye and Thompson's Pond. VI is from Montvale Canal, which takes the bulk of the water from the brook at a point above the pond, the two re-uniting again below, and is about three miles and a half below the chemical works. Mystic Pond is between four and five miles below V and VI.

From the point numbered VI, that is, from the canal at Montvale, samples were taken at intervals until the water returned to its alkaline re-action. The results of the examination were as follows:—

DATE.	LOCALITY.	Total Solid Matter dried at 100° C.	Acidity in equivalent of H ₂ SO ₄ .	Total Sulphuric Acid free and combined, reckoned as SO ₃ .	REMARKS.
1879.					
June 6	Canal at Montvale Avenue, Montvale	11.6	0.22	4.7	The residue of evaporation did not effervesce with acid.
June 7		13.9	0.37	-	
June 9		12.8	0.26	-	
June 10		11.6	0.22	-	
June 13		9.4	0.16	-	
June 15		10.1	{ Slightly alkaline.	{ -	Residue does not effervesce.
June 19		9.4	0.16	1.2	
June 30		7.7	{ Slightly alkaline.	-	
July 8		8.4	{ Slightly alkaline.	-	Residue does effervesce with acid.

While the water was acid, the residue of evaporation did not effervesce with acid, showing that a part, at any rate, of the sulphuric acid was neutralized by the carbonates in the water. It may also be noted, that some fragments of marble were put into some of the water No. IV., which had an acidity of 0.74: after standing for fifteen hours, the acidity had decreased to 0.11, and after standing for two and a half days the re-action was neutral or faintly alkaline.

Samples were taken from the upper end of Mystic Pond for several days, but no acid re-action was at any time perceptible.

OBSERVATIONS ON FRESH POND, CAMBRIDGE.

BY

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OBSERVATIONS ON FRESH POND, CAMBRIDGE.

THE present paper is a contribution to our knowledge in the matter of stored surface-waters. The observations recorded form a part of an investigation now in progress into the question, How far is the circulation due to difference of temperature of practical importance in such ponds and reservoirs as are usually employed in this region for purposes of water-supply? The investigation was prompted by views advanced by an eminent authority with which the experience of the writer led him to disagree. It is not, however, proposed to enter into a full discussion of this question at this time, but simply to present the results of certain observations which may be of interest, as the pond on which the observations were made is actually used for water-supply.

Fresh Pond covers an area of some two hundred acres, and serves as the source of water-supply of Cambridge, Mass., lying, in fact, partly within the city limits. The pond is fed mainly by the ground-water or by actual springs. Many analyses of the water have been made in previous years.¹ The present samples were taken at the entrance to the bay from which the water is pumped (two and one-quarter million gallons per day on the average during 1878),² about at the point where the letter "P" of "Fresh Pond" falls in the map opposite p. 372 of the Ninth Annual Report of the State Board of Health. The water at this part of the pond is, as a rule, from thirty-five to forty feet deep. The samples were taken in sets of three, one as near the bottom as possible, one at twenty feet from the surface, and one at two feet from the surface. An attempt was made to determine the depth of color in the different samples, but the color was

¹ See Ninth Annual Report of State Board of Health, 1878, pp. 338, 339. Also Report of the Special Committee on the Water-Supply of the City of Cambridge, 1879, pp. 43-49.

² Fourteenth Annual Report of Cambridge Water Board, 1879, p. 34.

so faint that the attempt was abandoned. Observations on the temperature at these various depths, as well as the results of the partial chemical examination, are included in the following tables.

TABLE I. — *Examination of Fresh Pond, Mass. Water taken Two Feet below the Surface.*

[Results expressed in Parts in 100,000.]

Number.	DATE.	Height of Water in Pond.	Temperature in Degrees, Centigrade.	Ammonia.	"Albuminoid Ammonia."	Total Solid Residue dried at 100° C.	Chlorine.
1878.							
1	May 4 .	16.40	16.5	0.002	0.018	12.4	1.41
4	" 14 .	—	14.5	0.003	0.015	13.1	1.23
7	June 4 .	16.11	19.	0.004	0.015	16.1	1.41
10	" 12 .	15.68	17.3	0.003	0.015	13.3	1.31
13	" 19 .	15.38	20.5	0.003	0.013	13.7	1.38
16	" 25 .	15.30	22.2	0.003	0.028	15.6	1.47
19	July 2 .	14.99	28.0	0.004	0.025	14.7	1.47
22	" 9 .	14.57	26.0	0.003	0.018	13.8	1.38
25	" 16 .	14.60	25.3	0.003	0.020	13.2	1.30
28	" 23 .	14.38	24.0	0.002	0.017	13.2	1.40
31	Aug. 6 .	14.25	24.0	0.004	0.020	11.7	1.44
34	" 13 .	14.75	24.0	0.004	0.022	12.0	1.37
37	" 20 .	14.67	24.0	0.004	0.019	11.0	1.36
40	" 27 .	14.54	22.3	0.002	0.020	11.7	1.31
43	Oct. 21 .	13.74	—	0.018	0.017	13.3	1.46
46	Nov. 7 .	13.66	9.5	0.031	0.017	11.5	1.22
49	Dec. 7 .	14.50	4.5	0.030	0.023	12.6	1.30
1879.							
52	Jan. 2 .	14.78	0.5	0.017	0.017	12.3	1.38
55	" 14 .	14.68	0.7	0.017	0.014	12.4	1.28
58	" 22 .	14.58	0.9	0.018	0.016	11.8	1.40
61	April 14 .	15.16	6.0	0.007	0.014	12.8	1.61
64	May 13 .	15.46	18.5	0.003	0.016	13.0	1.46

TABLE II. — *Examination of Fresh Pond, Mass. Water taken about Twenty Feet below the Surface.*

[Results expressed in Parts in 100,000.]

Number.	DATE.	Height of Water in Pond.	Temperature in Degrees, Centigrade.	Ammonia.	"Albuminoid Ammonia."	Total Solid Residue dried at 100° C.	Chlorine.
1878.							
2	May 4 .	16.40	12.5	0.002	0.017	12.1	1.42
5	" 14 .	—	14.5	0.003	0.014	13.3	1.27
8	June 4 .	16.11	16.5	0.005	0.015	14.4	1.39
11	" 12 .	15.68	16.8	0.003	0.016	13.7	1.31
14	" 19 .	15.38	16.8	0.006	0.016	14.4	1.37
17	" 25 .	15.30	16.6	0.009	0.016	13.6	1.42
20	July 2 .	14.99	16.7	0.012	0.024	14.9	1.33
23	" 9 .	14.57	16.4	0.010	0.018	13.9	1.40
26	" 16 .	14.60	16.8	0.007	0.021	13.8	1.25
29	" 23 .	14.38	16.8	0.012	0.017	13.8	1.36
32	Aug. 6 .	14.25	17.3	0.005	0.019	13.5	1.39
35	" 13 .	14.75	20.1	0.006	0.020	12.6	1.36
38	" 20 .	14.67	20.0	0.004	0.018	12.5	1.36
41	" 27 .	14.54	20.0	0.002	0.020	13.4	1.29
44	Oct. 21 .	13.74	—	0.018	0.017	12.9	1.44
47	Nov. 7 .	13.66	9.2	0.035	0.019	11.5	1.24
50	Dec. 7 .	14.50	4.3	0.029	0.024	12.2	1.34
1879.							
53	Jan. 2 .	14.78	1.0	0.017	0.016	12.0	1.38
56	" 14 .	14.68	1.3	0.016	0.014	12.2	1.30
59	" 22 .	14.58	2.0	0.018	0.013	12.0	1.40
62	April 14 .	15.16	5.0	0.004	0.013	12.6	1.62
65	May 13 .	15.46	13.0	0.003	0.016	13.0	1.44

TABLE III. — *Examination of Fresh Pond, Mass. Water taken about Thirty-five Feet below the Surface.*

[Results expressed in Parts in 100,000.]

Number.	DATE.	Height of Water in Pond.	Temperature in Degrees, Centigrade.	Ammonia.	"Albuminoid Ammonia."	Total Solid Residue dried at 100° C.	Chlorine.
1878.							
3	May 4	16.40	8.5	0.018	0.016	12.2	1.38
6	" 14	—	8.5	0.027	0.015	12.9	1.26
9	June 4	16.11	8.8	0.074	0.015	15.7	1.37
12	" 12	15.68	8.6	0.078	0.017	13.9	1.34
15	" 19	15.38	8.7	0.105	0.023	14.5	1.39
18	" 25	15.30	9.2	0.100	0.010	13.8	1.45
21	July 2	14.99	9.3	0.112	0.025	15.2	1.40
24	" 9	14.57	9.2	0.087	0.018	14.3	1.40
27	" 16	14.60	9.6	0.079	0.020	14.0	1.23
30	" 23	14.38	9.9	0.090	0.019	13.9	1.32
33	Aug. 6	14.25	10.1	0.068	0.021	13.3	1.35
36	" 13	14.75	10.0	0.095	0.021	13.9	1.42
39	" 20	14.67	10.2	0.129	0.018	13.6	1.34
42	" 27	14.54	10.0	0.099	0.023	14.2	1.37
45	Oct. 21	13.74	—	0.104	0.021	13.0	1.41
48	Nov. 7	13.66	8.7	0.037	0.019	11.9	1.22
51	Dec. 7	14.50	4.5	0.020	0.025	12.3	1.28
1879.							
54	Jan. 2	14.78	1.0	0.018	0.015	12.3	1.36
57	" 14	14.68	1.7	0.018	0.014	12.2	1.30
60	" 22	14.58	1.8	0.019	0.013	11.9	1.40
63	April 14	15.18	4.4	0.004	0.008	12.6	1.60
66	May 13	15.46	8.3	0.020	0.015	12.9	1.50

Although the observations were not taken at regular intervals or with as great frequency as might be wished, they have been plotted in the form of curves, and are thus presented in the accompanying diagram.

The chemical examination included the determination of the ammonia, "albuminoid ammonia," the chlorine, and the total solids obtained by evaporating the water and drying the residue at 100° C. In the case of no one of the series of results is there a marked progressive change except in the "ammonia;" nor with this exception is there, as a general rule, any marked difference in the water taken from different depths.

The results of the observations on temperature can be readily seen on the diagram, and little verbal description is necessary. It will be noticed that near the bottom of the pond the temperature is quite uniform from May to November, and drops rather suddenly to rise again in April. No measurements were made during February and March, on account of the ice, which prevented the use of boats, and did not allow safe passage on foot, so that it is impossible to say exactly when the observed rise of temperature begins. The surface-water is subject to much more variation, of course, and does indeed vary from day to day and at various hours of the same day; the water at twenty feet, which point was somewhat above the middle of the pond, had a tolerably uniform temperature during the early summer, becoming heated in August, and cooling thereafter.

If we compare together, as we are enabled to do by the curves in the diagram, the temperatures at the different depths observed at the same time, we see that during the eight months of the year, from April to November, the top-water is decidedly the warmer. Of course, with the difference in temperature, there is a difference in density; and if the pond were filled with pure water it is evident, that, in the absence of mechanically produced currents, the warmer water would remain on the top; with the difference of about fifteen degrees, which existed during July and August, the difference in density would be very considerable.¹ When the water begins to cool, the temperature falls throughout, and the cooling proceeds in such a way that the warmer and consequently the lighter water remains constantly at the top until November, after which and for some time the temperature is nearly uniform from top to bottom as far as I have observations. During the month of January, when the pond was covered with ice, the top water was somewhat cooler than the lower water; but still the top water is the lighter,

¹ The specific gravity of pure water at different temperatures has been determined by various observers with slightly different results. The following figures are those of Rossetti (*Annales de Chimie et de Physique*) [4], 17, p. 370.

0° = 0.999871	5° = 0.999990	10° = 0.999747
1° = 0.999928	6° = 0.999970	15° = 0.999160
2° = 0.999969	7° = 0.999933	20° = 0.998259
3° = 0.999991	8° = 0.999886	25° = 0.997120
4° = 1.000000	9° = 0.999824	

for the specific gravity of pure water at 2° , the bottom temperature, is 0.999969, and at 0.9° , the top temperature, is 0.999922. When the water begins to warm up in the spring after the ice has melted, the warming proceeds as the cooling did in the fall throughout the mass of the water, but in such a way that the upper water grows warmer and lighter more rapidly than that below.

In considering the water as pure water we shall not be led very far astray, because the determination of the total dissolved solids shows that, with a few exceptions noticed during the summer months, the water taken at the same time from the three depths does not show differences greater than the allowable error of analysis.

It should be here distinctly stated that the changes of temperature are certainly not the only causes which produce circulation in the water of a pond. Rain, wind, the continual entrance of ground-water into the pond, and the evaporation from the surface, the withdrawal of water for consumption or by natural channels, the unequal warming or cooling of the water in different portions of the pond, owing to differences in depth and to other circumstances, the constant moving-about of fish, the rising and falling of particles of suspended matter of nearly the same specific gravity as the water,¹ and many other causes, great and small, tend to mix the water and produce a uniform character. Considering, however, the effect of temperature alone, the present observations indicate that the greatest mixing owing to actual differences of temperature would take place in the winter, and while the ice was forming or formed; but it is to be noticed, that, after the considerable differences of temperature which we obtain during the summer, there is a nearly uniform temperature by the 1st of November. During the summer the difference of temperature would tend to lessen the amount of circulation from other causes; and we might expect, that, if any marked perceptible change took place, it would be likely to be in the fall.

¹ It has been noticed that in ponds subject to the growth of algæ, such as the *Clathrocystis*, described in Dr. Farlow's paper, these plants generally fall to the bottom before the ice begins to form. If a period of warm weather occurs, even after the ice has acquired considerable thickness, the plants in a more or less decomposed condition rise up to the under surface of the ice, and when the ice increases in thickness become frozen in, rendering it in some instances unsalable.

If now we consider the chemical character of the water, we shall find that in one respect there is something worthy of note, and that is in regard to the amount of ammonia. The absolute amount is, in any case, small, and in the curve the variations are shown on a larger scale than in the case of the "total solids." It will be noticed that there is a much greater amount of ammonia in the bottom water during the summer, but that about Nov. 1 there is a sudden decrease, and there is at the same time an increase in the amount in the upper water. This increase cannot be due simply to the fact that the lower temperature of the water enables it to hold more ammonia, because the bottom water which goes on growing cooler contains a less amount of ammonia than it has during the summer when decomposition has been more active. The fact of the increase of ammonia in the autumn has been noticed by other observers, and explanations have been suggested. Thus Mr. S. P. Sharples, the chemist of the Cambridge Water Board, says,¹—

"The amount of free ammonia in the [surface] water is small so long as plant-life is vigorous and healthy; but, so soon as this is checked by the frost in the fall, this [the ammonia] suddenly rises, from the fact that the plants commence to decay as soon as they are killed; and the amount of ammonia is also, no doubt, increased by the leaves that blow or fall into the pond, and there decay."

Professor E. S. Wood in a recent report² says, —

"The large increase in the amount of ammonia in the autumn may be explained in many ways. A portion may be due to decaying vegetation, but not the whole; since we do not observe so large an increase in other ponds which are subjected to the same conditions as Fresh Pond, so far as decaying vegetation is concerned. It may also be partly explained by the surface washings from the cultivated land, caused by heavy rains in the fall and spring, at which seasons the manure is applied to the land."

No doubt the general statements made by Dr. Wood are true; but the facts just noted offer another explanation of this well-marked increase of ammonia in the fall, — namely, that the very nearly uniform temperature which exists throughout the mass of the pond from about the 1st of

¹ Fourteenth Annual Report of Cambridge Water Board, 1878, p. 9.

² Report of the Special Committee on the Water Supply of the City of Cambridge, 1879, p. 50.

November, or somewhat earlier, gives the greatest opportunity for the mixing of the water on account of diffusion and other general causes, and at the same time slight differences of temperature caused by the cooling of the surface-water and by the alternations of cold and warm weather prior to the formation of the solid crust of ice will have very much more effect in producing currents than in summer when there is a considerable difference in temperature between the bottom and the top.

Owing to the slightly alkaline character of the water, the ammonia is probably all the while escaping as ammonia-gas or as carbonate of ammonia, and some is also being oxidized to nitrates; and, as a result, it would appear that, in the early spring, the amount is comparatively small throughout the mass of the water. As the temperature rises, the increase of decomposition causes an increase of ammonia; and as the tendency of the water to circulate becomes less and less, owing to the continually increasing difference of temperature and specific gravity, the ammonia accumulates in the bottom water.

In order to prove the truth of this theory, observations over a more extended period are necessary. We should not, of course, find exactly the same temperatures at corresponding times each year, but we should expect to discover the same general condition of things. Such observations as I have been able to make or have made since the period covered by the diagram are here presented, and do not disagree essentially with those of the previous year.

TABLE IV. — *Examination of Fresh Pond, Mass. Temperature and Ammonia at Different Depths.*

DATE.	Depth from Surface.	Temperature in Degrees, Centigrade.	Ammonia in parts in 100,000.	
1879.				
July 16 . .	2 feet	27.2	-	} After a heavy rain.
" 16 . .	20 "	17.0	-	
" 16 . .	35 "	11.0	-	
Aug. 19 . .	2 "	21.2	0.008	
" 19 . .	20 "	20.8	0.009	
" 19 . .	30 "	11.0	0.068	
Oct. 2 . .	2 "	18.8	0.004	
" 2 . .	20 "	16.3	0.005	
" 2 . .	31 "	10.0	0.016	
1880.				
Jan. 5 . .	2 "	2.0	0.029	} Ice about 3 inches thick.
" 5 . .	20 "	2.3	-	
" 5 . .	34 "	2.7	0.086	
" 26 . .	2 "	2.8	0.028	} Ice about 6 inches thick.
" 26 . .	18 "	3.0	0.027	
" 26 . .	30 "	3.2	0.029	

We notice a rather curious fact,—that the water taken through the ice in January, 1880, has been much warmer than it was in January, 1879. This may be explained because we have had this winter a great deal of warm and open weather, and the water which enters the pond is probably warmer. As last year, the water is slightly but unmistakably warmer at the bottom than at the top.

It may be well in this connection to correct the current statement of text-books on chemistry and physics, which state generally that in lakes and rivers "the temperature of the whole mass is reduced to 4° C., after which the surface-water never sinks, however much it may be cooled, as it is always lighter than the deeper water at 4°. Hence ice is formed only at the top, the mass of water retaining the temperature of 4°."¹ This statement is not true in the case of waters of

¹ This is quoted from the recently published *Treatise on Chemistry*, by Roscoe and Schorlemmer.

moderate depth, as shown by the formation and persistence of anchor-ice in ponds and streams. Moreover, the records of the United-States Signal Service show that at the points where observations are regularly made, the water is frequently of the temperature of 32° F. (0° C.) *from top to bottom* for several days before the surface is frozen over.¹ The observations here put on record show that even in ponds where the water is thirty-five feet deep, the temperature at the bottom may fall considerably below 4° C.; and I have found the same thing to be true in other ponds, where the depth is as much as seventy feet.

REMARKS ON METHODS OF COLLECTION AND OBSERVATION.

Collection of Samples. — The water was collected in glass bottles of two and one-half liters capacity, which were lowered to the required depth, and then opened by a cord attached to the stopper.

Observations of Temperature. — A centigrade thermometer was inserted in the bottle used for the collection of the water; and after the bottle had filled it was allowed to remain until there was certainty that the mass of the bottle and the thermometer had acquired the actual temperature of the water. The thermometers used were graduated to degrees, and the tenths were estimated; the error in reading could hardly in any case be greater than 0.2°, and as the thermometers were compared with standards and duly corrected, the total error would not be much greater than 0.2°. The curves of temperature on the diagram were plotted from the data of the table; of course they would be the same if Fahrenheit degrees were employed. For convenience it may be said, however, that

0° C. = 32° F.	15° C. = 59° F.
5° C. = 41° F.	20° C. = 68° F.
10° C. = 50° F.	25° C. = 77° F.

Since the observations recorded above were made, I have procured and am now using a Negretti and Zambra deep-sea thermometer which has been very accurately corrected. I have found, however, that the method described above gives

¹ These observations are made at lake and river stations near the shore, and seldom in water over fifteen feet in depth, and no observations are taken after ice has formed.

results which agree with those obtained with the deep-sea thermometer, and for shallow waters, with proper care, answers well enough.

Chemical Examination.—In a water like that of Fresh Pond, the “total solid residue” in two samples of water taken at the same time and from the same point would frequently differ by as much as 0.25 or perhaps even 0.5 part; so that it is only during June, July, and August that the observed differences in the samples at different depths are really to be considered essential. The determinations of chlorine were made by the usual volumetric method, and the results are plotted on a scale ten times as great as that employed in the case of the “total solids.” Here again the difference between the water at different depths is in almost every instance within the allowed error of analysis. The ammonia and “albuminoid ammonia” are determined by the now well-known Wanklyn method. By ammonia is understood the amount obtained by distilling the water with carbonate of soda; and, by the “albuminoid ammonia,” the amount which is given off by a subsequent distillation with an alkaline solution of permanganate of potash.

For aid in carrying on this investigation, I am indebted to my former assistants, Mr. Thomas F. Stimpson, S. B., now chemist of the Silver Spring Bleaching and Dyeing Company, Providence, R. I.; and Mr. John E. Hardman, S. B., now in charge of smelting-works at Red Cliff, Col.

ON THE EXAMINATION OF MYSTIC WATER.

WITH REMARKS ON
FRANKLAND'S METHOD OF WATER ANALYSIS.

BY
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ON THE EXAMINATION OF MYSTIC WATER.

WITH REMARKS ON
FRANKLAND'S METHOD OF WATER ANALYSIS

THIS paper presents in tabular form the results of the examinations of Mystic water, which have been made in the laboratory of the Massachusetts Institute of Technology during the past year. The samples have been furnished by Mr. Joseph P. Davis, city engineer; the water was drawn at the office of the Mystic Water Board in Charlestown. The analytical work has been done under my direction by my assistant, Mr. W. W. MacFarlane, S. B., and I have full confidence in the accuracy of the results.

The examinations were made mainly for the sake of obtaining a wider experience in the application to our New England waters of the method of analysis devised by Frankland and Armstrong, and employed by the Rivers Pollution Commission in the large number of analyses made in their investigations into the waters of Great Britain.

The table (Table I.) contains the results obtained by this method,—the “organic carbon” and “organic nitrogen,”—and also the results obtained by the more commonly employed method of Wanklyn, according to which the amount of nitrogenous organic matter is indicated by the “albuminoid ammonia.” As Frankland’s method has hitherto been seldom used in this country, and has not been employed by the State Board of Health, it will not be out of place to make some remarks with reference to the method itself, and the interpretation of the results obtained by means of it.

By this method a certain quantity of the water is evaporated to dryness with suitable precautions; the dry residue is then subjected to a process of organic analysis, and is burned in a closed vessel in such a manner as to convert all the

TABLE I. — *Examination of Mystic Water.*

[Results expressed as so many parts by weight in 100,000 parts by weight of the water.]

DATE.	Organic Carbon.	Organic Nitrogen.	Sum of Organic Elements.	Ratio. Carbon Nitrogen	Ammonia.	"Albuminoid Ammonia."	Total Solids.	After Filtration through Paper.		
								Organic Carbon.	Organic Nitrogen.	Total Solids.
1879.										
June 19 . . .	0.390	0.083	0.473	4.7	-	-	-	-	-	-
" 26 . . .	0.395	0.088	0.483	4.5	-	-	-	-	-	-
July 3 . . .	0.445	0.056	0.501	7.9	-	-	9.6	-	-	-
" 10 . . .	0.762	0.100	0.862	7.6	-	-	10.0	0.436	0.077	-
" 17 . . .	0.716	0.112	0.828	6.4	-	-	10.2	-	-	-
" 24 . . .	-	-	-	-	0.004	0.033	10.5	0.381	0.043	9.7
" 31 . . .	0.732	0.126	0.908	6.2	0.005	0.037	10.8	0.421	0.038	9.9
Aug. 7 . . .	0.727	0.082	0.809	8.9	0.004	0.033	-	-	-	-
" 14 . . .	0.433	0.065	0.548	7.4	0.004	0.024	10.2	0.378	0.040	9.7
" 21 . . .	0.400	0.107	0.507	3.7	0.005	0.024	10.4	0.367	0.039	10.1
" 28 . . .	0.455	0.100	0.555	4.5	0.005	0.023	10.7	-	-	10.4

Sept. 4	.	.	-	-	-	-	-	0.003	0.019	9.8	0.389	0.064	9.6
" 11	.	.	0.407	0.112	0.519	-	3.6	0.004	0.021	9.5	-	-	-
" 18	.	.	0.330	0.081	0.411	4.1	0.002	0.002	0.020	9.7	-	-	-
" 25	.	.	0.352	0.062	0.414	5.7	0.004	0.004	0.020	9.6	-	-	-
Oct. 2	.	.	0.364	0.059	0.423	6.2	0.004	0.004	0.016	9.8	-	-	-
" 9	.	.	0.328	0.022	0.350	14.5	0.007	0.007	0.015	10.1	-	-	-
" 16	.	.	0.315	0.021	0.336	15.0	0.001	0.001	0.013	9.6	-	-	-
" 23	.	.	0.316	0.055	0.371	5.7	0.003	0.003	0.013	9.7	-	-	-
" 30	.	.	0.323	0.063	0.386	5.1	-	-	-	-	-	-	-
Nov. 7	.	.	0.301	0.056	0.357	5.4	0.005	0.005	0.013	10.0	-	-	-
" 20	.	.	0.374	0.056	0.430	6.6	0.005	0.005	0.009	9.5	-	-	-
Dec. 4	.	.	0.275	0.022	0.297	12.5	0.009	0.009	0.011	9.9	-	-	-
1880.													
Jan. 1	.	.	0.315	0.046	0.361	6.8	0.012	0.012	0.013	9.9	-	-	-
" 15	.	.	0.313	0.054	0.367	5.8	0.012	0.012	0.011	10.2	-	-	-
Average	.	.	0.429	0.070	0.499	6.1	0.005	0.005	0.019	10.0	-	-	-

carbon and *nitrogen* of the organic matter into gaseous substances, which are collected and measured. The carbon and nitrogen are spoken of as *organic carbon* and *organic nitrogen* respectively, and they are sometimes taken together and spoken of as the *organic elements*. The method is difficult and tedious, requiring the use of expensive and frangible apparatus, and consuming considerable time: for these reasons it can never be popular. Moreover, as is the case with every method employed for obtaining indications of the amount and character of the organic matter in a water, the results must be interpreted by a knowledge of the source from which the water is derived, and of its surroundings. It must also be borne in mind, that the sum of the amounts of organic carbon and organic nitrogen does not represent the actual *amount of organic matter* present, for most organic substances which occur in natural waters contain in addition a larger or smaller amount of oxygen and of hydrogen; how much, in any particular case, we cannot tell. In interpreting the results, it is felt that great importance attaches to the relative proportion of carbon to nitrogen; for it is, in general, true that organic matter of vegetable origin contains a larger proportion of carbon, while organic matter of animal origin contains a larger proportion of nitrogen. This statement, however, cannot be taken without some qualification, as will appear farther on.

In studying the figures in the foregoing table we see very clearly one fact to which I have frequently called attention; namely, the great variation to which surface-waters are subject, and especially in respect to the organic matter which they contain. On this account it is seldom possible to form a just idea of the general character of such a water from a single examination. This variation is rendered very large in the present instance, because during the summer there was in Mystic Pond, and in the water as drawn in the city, a very large amount of the microscopic algæ, which will be more particularly described by Dr. Farlow in subsequent pages.

In order that the effect of their presence may appear more clearly, I have prepared the following table (Table II.), in which we have the results presented, first in monthly averages, and then in averages for certain periods into which

there seemed to be a natural division. The algæ became numerous enough to awaken complaint and apprehension after the middle of July, and the trouble was at its height in the latter part of July and during August. For convenience I have put into the same table the results of the "albuminoid ammonia" determinations, to which reference will be made later.

TABLE II. — *Examination of Mystic Water.*

[Results expressed as so many parts by weight in 100,000 parts by weight of the water.]

DATE.	No. of Samples.	Sum of the Organic Elements.	"Albuminoid Ammonia."
1879.			
June. . . .	Average of 2 samples	0.478	—
July	" " 4 "	0.775	0.035 ¹
August	" " 4 "	0.605	0.026
September	" " 3 "	0.448	0.020
October	" " 5 "	0.333	0.014
November	" " 2 "	0.393	0.011
December	" " 1 "	0.297	0.011
1880.			
January	" " 2 "	0.364	0.012
June 19 to July 3 .	" " 3 "	0.486	—
July 10 to Aug. 7 .	" " 4 "	0.852	0.034
Aug. 14 to Sept. 11 .	" " 4 "	0.526	0.022
Sept. 18 to Jan. 15 .	" " 12 "	0.375	0.014

Even in the absence of any abnormal condition such as was caused this summer by the growth of algæ, there is at times a considerable variation in the amount and character of the organic matter in the water, as for instance, in October, 1879, when on the 9th and 16th of the month the nitrogen was very much below the usual amount, as again on Dec. 4. That such changes should take place, is not at all surprising, although we may not be able to explain the reason why in each particular case. The water is taken from near the surface of the pond, flows in a conduit for some distance to the pumping-station, is pumped into an open reservoir, and thence distributed into the city. We

¹ Average of two samples.

know that the organic matter in natural water undergoes change with greater or less rapidity owing to the differences of temperature, to the action of the wind, to the length of time during which the water is exposed to the sun and air in the reservoir, and to other such causes.

That the considerable variation in the amount and relative proportion of the organic carbon and organic nitrogen is not peculiar to Mystic water, may be seen from the Tables III. and IV.

TABLE III. — *Examination of Glasgow Water by PROFESSOR BISCHOF.*

[Results expressed as so many parts by weight in 100,000 parts by weight of the water.]

DATE.				Organic Carbon.	Organic Nitrogen.	Ratio. Carbon Nitrogen	Sum of Organic Elements.
1873.							
May	12	.	.	0.204	0.017	12.0	0.221
June	16	.	.	0.181	0.016	11.3	0.197
July	18	.	.	0.192	0.008	[24.0]	0.200
Aug.	1	.	.	0.209	0.011	19.0	0.220
Sept.	1	.	.	0.156	0.047	3.3	0.203
Oct.	14	.	.	0.256	0.028	8.2	0.284
Nov.	24	.	.	0.177	0.085	5.1	0.212
1874.							
Jan.	15	.	.	0.154	0.021	7.3	0.175
Feb.	5	.	.	0.251	0.008	[31.4]	0.259
March	10	.	.	0.185	0.007	[26.4]	0.192
April	1	.	.	0.169	0.003	[56.3]	0.172
May	5	.	.	0.235	0.011	[21.3]	0.246
Average	.	.	.	0.197	0.018	10.9	0.215

Table III. contains the results of monthly examinations of the water of Glasgow, Scotland, as reported by Professor Gustav Bischof of the Andersonian University. The water comes from an unpolluted Highland lake, Loch Katrine, and flows some thirty-six miles in a masonry conduit. Table IV., which, like No. III., is compiled from the Sixth Report of the Rivers Pollution Commission, shows the variation in the water of the several companies which supply London with filtered river-water. These are not *monthly averages*, but the results of the examination of single samples taken at monthly intervals.

TABLE IV. — *Variation in Monthly Samples of London Water, 1873.*

NAME OF COMPANY.	ORGANIC CARBON.			ORGANIC NITROGEN.		
	Maximum at any one time.	Minimum at any one time.	Mean of 12 Samples.	Maximum at any one time.	Minimum at any one time.	Mean of 12 Samples.
Chelsea . . .	0.447	0.121	0.197	0.067	0.013	0.034
West Middlesex, .	0.341	0.114	0.173	0.055	0.015	0.028
Southwark . . .	0.396	0.118	0.186	0.060	0.020	0.030
Grand Junction, .	0.412	0.117	0.183	0.050	0.016	0.032
Lambeth . . .	0.449	0.130	0.206	0.065	0.021	0.040
New River . . .	0.257	0.059	0.107	0.032	0.010	0.018
East London . .	0.333	0.109	0.175	0.082	0.015	0.035

In order to judge of the general character of the Mystic water, as shown by the results of Frankland's method of analysis, we have the necessary material in Table V., from which it appears that the total amount of organic matter as indicated by the organic carbon and nitrogen would be somewhat less than in Cochituate, were it not for the increase brought about by the development during the summer months of the algæ, to which allusion has been made. It appears, however, that, on the whole, there is a *larger proportion* of nitrogen in the Mystic than in the Cochituate water, and this agrees with what we know of the character of the respective water-sheds. Considering also that the total dissolved substances, organic and inorganic, amount to twice as much in the Mystic as in the Cochituate supply, we must regard the latter as the better water; the examination shows, however, as far as chemical examination can show, that, in spite of the polluting influences which have been at work in the ponds and streams supplying Mystic Pond, the water in its normal condition is still good, and well suited for domestic supply.

Although considerable importance is attached to the relation of carbon to nitrogen as indicating the character of the organic matter, too much stress cannot be laid upon this ratio. Frankland found that, in waters rendered impure by the presence of peaty matter, the average amount of carbon was to the amount of nitrogen as 11.9 : 1, while the proportion in sewage was as 1.8 : 1. Frankland found, however, that the influence of oxidation on peaty matter, i.e., vegeta-

TABLE V. — *Comparison of Mystic with Other Waters.*

[Results expressed in Parts in 100,000.]

DATE.	DESCRIPTION.	Organic Carbon.	Organic Nitrogen.	Ratio. Carbon Nitrogen
June, 1879, to Jan. 1880.	Mystic water. Average of 23 samples . . .	0.429	0.070	6.1
Sept. 18, 1879, to Jan. 15, 1880.	Mystic water. Average of 12 samples ¹ . . .	0.325	0.050	6.5
Jan. to June, 1879.	Boston water (Cochituate Lake and Sudbury River). Average of 22 samples ² . . .	0.408	0.052	7.9
June, 1879, to Jan. 1880.	Boston water. Average of 24 samples ³ . . .	0.424	0.048	8.8
Jan. to June, 1879.	Fresh Pond, Cambridge. Average of 11 samples ⁴ . . .	0.417	0.074	5.6
May, 1873, to May, 1874.	Glasgow water. Average of 12 samples ⁵ . . .	0.197	0.018	10.9
	Unpolluted upland surface water. Average of 195 samples ⁶ . . .	0.322	0.032	10.0

ble matter containing a considerable proportion of carbon, is to decrease the amount of carbon, while by the oxidation of animal matter, i.e., matter containing a considerable proportion of nitrogen, it is the nitrogen which decreases most rapidly. "It is thus evident that the proportions of nitrogen to carbon in soluble vegetable and animal organic matters *vary in opposite directions during oxidation*,—a fact which renders more difficult the decision as to whether the organic matter present in any given sample of water is of animal or vegetable origin."

It is not impossible that the smaller ratio observed in the cases of Mystic Lake and Fresh Pond may be due in part to the fact that a larger proportion of the water comes in through the bottom and sides of the pond, and the water thus entering contains a smaller relative amount of nitrogen.

¹ These are the samples taken after the algæ became less abundant. They are included also in the previous twenty-three.

² Third Annual Report of the Boston Water Board, 1879, p. 35.

³ From unpublished results.

⁴ These samples were taken from the pond itself at various depths, and do not claim to represent the average character of the water as delivered in Cambridge, Mass.

⁵ Sixth Report of Rivers Pollution Commission, p. 347. Already quoted in Table III.

⁶ Sixth Report of Rivers Pollution Commission, p. 425.

It is to be said, however, that while Fresh Pond is supplied in great measure from underground sources, the bulk of the water entering Mystic Lake comes from the Abajonna River, and it is said that the rainfall affects the Mystic basin more rapidly than that of Lake Cochituate.

On the whole, I believe that the ratio obtained from the average of a considerable number of determinations gives a valuable means of judging of a *surface* water; in the case, however, of well-waters or of ground-waters generally, where the amount of organic matter is very small, I have been led by a study of the results of the Rivers Pollution Commission, and from the somewhat limited number of analyses that I have myself accumulated, to the conclusion that we cannot attach any weight to the ratio of carbon to nitrogen, but must form our judgment from the "sum of the organic elements." For the same reason I have bracketed certain figures in Table III., lest they should be thought to mean more than they do. It is evident that a very small error in the amount of nitrogen would make an appreciable difference in the ratio. An error of 0.005 part in the nitrogen is the allowed limit, although duplicate determinations usually agree closer than this, and frequently they agree exactly as far as the third place of decimals. The carbon should agree, in duplicate determinations, to the second place.

Finally, I have put into Table VI. the average of the ammonia and "albuminoid ammonia" determinations on the Mystic and several other waters.

TABLE VI. — *Comparison of Mystic with Other Waters.*

DATE.	Description.	Ammonia.	"Albuminoid Ammonia."
July, 1879, to Jan. 1880.	Mystic water. Average of 19 samples	0.005	0.019
Sept. 1879, to Jan. 1880.	Mystic water. Average of 11 samples ¹	0.006	0.014
July, 1877, to Apr. 1879.	Boston water. Average of 40 samples	0.004	0.015
May, 1878, to May, 1879.	Fresh Pond, surface water. Average of 22 samples	0.008	0.017

¹ These are the samples taken after the algae became less abundant. They are included also in the previous nineteen.

In Table II. we notice that in the lower group of averages the amounts of "albuminoid ammonia" bear the same relation to each other as the amounts of the "organic elements." This is purely accidental; and a study of Table I., or even of the monthly averages in Table II., will show that there is no coincidence or uniformity of relation. If both methods are equally accurate, this shows that in addition to the organic matter which furnishes the "albuminoid ammonia," there is always other nitrogenous matter in variable quantity.

It may be said that while as a chemical method that of Frankland is superior to that of Wanklyn, and while it is more satisfactory in following out the changes of surface-waters, as a rule, — for practical purposes, — the Wanklyn method suffices, provided the results are interpreted with a proper knowledge of the history of the water under examination, and Frankland's method does not dispense with the necessity for such knowledge.

APR 27 1881

JUL 5 1887

OCT 26 1880

APR 19 1889

DEC 5 1889

AUG 9 1894

APR 5 1899

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